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## Description

PHOSPHORESCENT PHOSPHOR AND METHOD OF MANUFACTURING THEREOF

## Technical Field

The present invention relates to a phosphorescent phosphor, and more particularly to a phosphorescent phosphor having excellent afterglow characteristics when excited under low illumination.

## Background Art

Generally, the afterglow time of a phosphor is extremely short, i.e., the light emitted from the phosphor rapidly decays after external excitation is stopped. However, after being excited with ultraviolet radiation or the like, some phosphors rarely show afterglow which can be perceived by the naked eye for a considerable time (ranging from several tens of minutes to several hours) even after the excitation is stopped. Such phosphors are called phosphorescent phosphors or phosphorous materials as distinguished from normal phosphors.

Sulfide phosphors such as  $\text{CaS:Bi}$  (which emits violet blue light),  $\text{CaSrS:Bi}$  (which emits blue light),  $\text{ZnS:Cu}$  (which emits green light) and  $\text{ZnCdS:Cu}$  (which emits yellow or orange light) are known as such phosphorescent phosphors,. However, any of these sulfide phosphors has many problems from a practical viewpoint, e.g., chemical instability, poor photo-resistance. Moreover, even when this zinc sulfide phosphor is used for

a luminous clock, afterglow allowing the time to be perceived by the naked eye lasts only about 30 minutes to 2 hours.

Thus, the applicant invented a phosphorescent phosphor comprising a compound expressed by  $MAI_2O_4$  as a matrix, in which M is at least one metal element selected from the group consisting of calcium, strontium and barium, as a phosphorescent phosphor which has afterglow characteristics that last much longer than those of commercially available sulfide phosphors, chemical stability and excellent photo-resistance for a long time, and obtained a patent thereof (see Japanese Patent No. 2543825 Publication: patent document 1).

Owing to the invention of the aluminate phosphorescent phosphor described in the patent publication, it has become possible to provide a long-afterglow phosphorescent phosphor which has afterglow characteristics that last much longer than those of conventional sulfide phosphors, chemical stability due to an oxide, excellent photo-resistance and broad applicability to various usage.

#### Disclosure of the Invention

However, further market needs, especially needs for safety applications using the phosphorescent phosphor in low illumination environments, such as release handles for escape in automobile trunks, and safety signs for escape guidance in the interiors of subway systems, tunnels, ships, airplanes and the like have grown, and high afterglow luminance

characteristics have been required in excitation conditions at lower illumination.

For example, low illumination conditions, i.e., excitation for 60 minutes at 5ft-c (approx. 54 lx), are regulated in UL 924 "Emergency Lighting and Power Equipment" of the UL standard, and low illumination conditions, i.e., excitation for 24 hours at 25 lx, are regulated in ISO 15370:2001 "Ships and marine technology · Low-location lighting on passenger ships · Arrangement" of the ISO standard.

The present invention has been made in view of such a situation, and its object is to provide a phosphorescent phosphor having excellent afterglow luminance characteristics, particularly initial afterglow luminance characteristics, even under the excitation condition of low illumination, compared to conventional strontium aluminate phosphorescent phosphors of the same type, and a method of manufacturing thereof.

Thus, in view of the above-described situation, the present inventor obtained a phosphorescent phosphor having excellent afterglow luminance characteristics compared to conventional strontium aluminate phosphorescent phosphors especially when excited under low illumination, by optimizing the amounts of europium (Eu) doped as an activator and dysprosium (Dy) doped as a co-activator, and further optimizing the composition ratio of strontium (Sr), and aluminum (Al) as structural elements of a matrix in the strontium aluminate

phosphorescent phosphor described in the above-described patent publication.

(1) First Invention

A phosphorescent phosphor according to a first invention of the present invention is a phosphorescent phosphor comprising a compound expressed by  $\text{SrAl}_2\text{O}_4$  as a matrix, wherein europium (Eu) is doped to the matrix as an activator, and dysprosium (Dy) is doped to the matrix as a co-activator, characterized in that an amount of the doped europium (Eu) is more than 1.5% and 5% in terms of mol% relative to a total mole number of strontium (Sr), europium (Eu) and dysprosium (Dy), an amount of the doped dysprosium (Dy) ranges  $0.4 \leq \text{Dy}/\text{Eu} \leq 2$  in terms of a molar ratio relative to europium (Eu), and a ratio of aluminum (Al) ranges from 2.02 to 2.4 in terms of a molar ratio relative to the total mole number of strontium (Sr), europium (Eu) and dysprosium (Dy).

Then, first of all, europium (Eu) is doped as an activator in the amount more than 1.5% and not more than 5% in terms of mol% relative to the total mole number of strontium (Sr), europium (Eu) and dysprosium (Dy) and dysprosium (Dy) is doped as a co-activator in the amount of  $0.4 \leq \text{Dy}/\text{Eu} \leq 2$  in terms of a molar ratio relative to europium (Eu), whereby the amount of doped europium contributing to fluorescent luminance characteristics or initial afterglow luminance characteristics is increased and optimized compared to the amount of doped dysprosium contributing to afterglow luminance characteristics. Therefore, initial afterglow luminance

characteristics under the excitation condition of low illumination are improved, resulting in afterglow luminance characteristics superior to those of conventional phosphorescent phosphors.

Further, since the ratio of aluminum (Al) ranges over 2.0 and not more than 2.4 in terms of a molar ratio relative to the total mole number of strontium (Sr), europium (Eu) and dysprosium (Dy), a crystal structure is distorted to facilitate formation of a trap by making the ratio of aluminum not less than 2.02 which is greater than a stoichiometry ratio of 2.0, and therefore initial afterglow luminance characteristics under the excitation condition of low illumination are improved, resulting in afterglow luminance characteristics further superior to those of conventional phosphorescent phosphors.

Here, first of all, if the amount of doped europium as an activator is 1.5% or less in terms of mol% relative to the total mole number strontium (Sr), europium (Eu) and dysprosium (Dy), the amount of doped europium is so small that the initial afterglow luminance characteristics are inadequate equivalent to or inferior to those of conventional phosphorescent phosphors which is not preferable. Further, if the amount of doped europium as an activator is greater than 5%, the afterglow luminance decreases generally due to concentration quenching, and initial afterglow luminance characteristics under the excitation condition of low illumination deteriorate accordingly. Thus, the optimum

doped amount of europium is more than 1.5% and not more than 5%.

Then, if the amount of doped dysprosium as a co-activator is less than 0.4 in terms of a molar ratio relative to europium, i.e.,  $Dy/Eu < 0.4$ , the amount of doped dysprosium contributing to afterglow luminance characteristics is not sufficient relative to the amount of doped europium for obtaining excellent initial afterglow luminance characteristics, and therefore desirable initial afterglow luminance characteristics cannot be obtained. Moreover, if the amount of doped dysprosium is greater than 2 in terms of a molar ratio relative to europium, i.e.,  $2 < Dy/Eu$ , the amount of doped europium contributing to fluorescent luminance characteristics or initial afterglow luminance characteristics is less than the amount of doped dysprosium contributing to afterglow luminance characteristics, and therefore fluorescent luminance characteristics and initial afterglow luminance characteristics deteriorate and desirable initial afterglow luminance characteristics cannot be obtained.

Thus, the amount of doped europium as an activator is more than 1.5% and not more than 5% in terms of mol% relative to the total mole number of strontium (Sr), europium (Eu) and dysprosium (Dy), and further the amount of dysprosium doped as a co-activator ranges  $0.4 \leq Dy/Eu \leq 2$  in terms of a molar ratio relative to europium, whereby a phosphorescent phosphor having improved initial afterglow characteristics under the

excitation condition of low illumination and hence having initial afterglow luminance characteristics superior to those of conventional phosphorescent phosphors can be obtained.

Moreover, if the ratio of aluminum (Al) is less than 2.02 in terms of a molar ratio relative to the total mole number of strontium (Sr), europium (Eu) and dysprosium (Dy), i.e.,  $Al/(Sr+Eu+Dy) < 2.02$ , the ratio of aluminum is almost equal to or less than the stoichiometry ratio of 2.0, and therefore the afterglow luminance characteristics thereof are almost equivalent to or inferior to those of conventional phosphorescent phosphors. Moreover, if the ratio of aluminum (Al) is greater than 2.4 in terms of a molar ratio, i.e.,  $2.4 < Al/(Sr+Eu+Dy)$ , the occurrence ratio of by-products increases, and the luminance decreases accordingly, which is not preferable.

Thus, the ratio of aluminum (Al) ranges from 2.02 to 2.4 in a molar ratio relative to the total mole number of strontium (Sr), europium (Eu) and dysprosium (Dy), whereby a phosphorescent phosphor having improved initial afterglow luminance characteristics under the excitation condition of low illumination and hence having afterglow luminance characteristics further superior to those of conventional phosphorescent phosphors can be obtained.

According to the phosphorescent phosphor according to the first invention, the amount of doped europium contributing to fluorescent luminance characteristics or initial afterglow luminance characteristics is increased and optimized compared

to the amount of doped dysprosium contributing to afterglow luminance characteristics, and the ratio of aluminum is made not less than 2.02 which is greater than the stoichiometry ratio of 2.0 so that a crystal structure is distorted, and therefore afterglow luminance characteristics under the excitation condition of low illumination are improved, thus making it possible to obtain afterglow luminance characteristics superior to those of conventional phosphorescent phosphors.

(2) Second Invention

A method of manufacturing an alkaline-earth metal aluminate phosphorescent phosphor according to a second invention of the present invention is characterized in that an aluminum (Al) compound, a strontium (Sr) compound, a europium (Eu) compound and a dysprosium (Dy) compound are mixed so that molar ratios of the elements meet following requirements:

$$0.015 < \text{Eu} / (\text{Sr} + \text{Eu} + \text{Dy}) \leq 0.05,$$

$$0.4 \leq \text{Dy} / \text{Eu} \leq 2,$$

$$2.02 \leq \text{Al} / (\text{Sr} + \text{Eu} + \text{Dy}) \leq 2.4, \text{ and}$$

a resultant mixture is fired in a reductive atmosphere, and then cooled and ground.

According to the method of manufacturing an alkaline-earth metal aluminate phosphorescent phosphor according to the second invention, an alkaline-earth metal aluminate phosphorescent phosphor having improved afterglow luminance characteristics under low-illumination excitation



conditions and hence having afterglow luminance characteristics superior to those of conventional phosphorescent phosphors can be manufactured.

### (3) Third Invention

A method of manufacturing an alkaline-earth metal aluminate phosphorescent phosphor according to a third invention of the present invention is the method of manufacturing an alkaline-earth metal aluminate phosphorescent phosphor according to the above-described second invention, characterized in that a boron compound as flux is added to a raw material and the resultant mixture is fired. Then, by adding a boron as flux compound to a raw material and firing the resultant mixture, an excellent alkaline-earth metal element aluminate phosphorescent phosphor can be manufactured at even a low firing temperature. Furthermore, boric acid ( $\text{H}_3\text{BO}_3$ ) is suitably used as the boron compound, but any boron compound other than boric acid brings about a similar effect. Moreover, the amount of boron compound to be added is preferably about 0.01 to 10% , more preferably about 0.5 to 3% of the total mass of raw material.

Here, if the amount of boron compound to be added is greater than 10% of the total mass of raw material, the fired material is tightly sintered, and therefore grinding becomes difficult and the luminance decreases due to grinding. Therefore, the amount of boron compound to be added is preferably 0.01 to 10% of the total mass of raw material.

### Brief Description of the Drawings

Fig. 1 is a powder X-ray diffraction analysis chart of Sample 2-(6).

### Best Mode for Carrying Out the Invention

Steps of manufacturing a phosphorescent phosphor in one embodiment of the present invention will be described below.

First, strontium carbonate ( $\text{SrCO}_3$ ) as raw materials of strontium (Sr), europium oxide ( $\text{Eu}_2\text{O}_3$ ) as a raw material of europium (Eu) as an activator is doped, and dysprosium oxide ( $\text{Dy}_2\text{O}_3$ ) as a raw material of dysprosium (Dy) as a co-activator is also doped. An amount of europium (Eu) doped at this time is more than 1.5% and not more than 5% in terms of mol% relative to a total mole number of strontium, europium and dysprosium, and an amount of dysprosium (Dy) doped ranges from 0.4 to 2 in terms of a molar ratio relative to europium (Eu). Further, as a raw material of aluminum (Al), alumina ( $\text{Al}_2\text{O}_3$ ) is added so that a molar ratio of aluminum ranges from 2.02 to 2.4 relative to the total mole number of strontium, europium and dysprosium, boric acid ( $\text{H}_3\text{BO}_3$ ), e.g., is added thereto as a boron compound as flux in an amount of about 0.01 to 10% relative to the total mass of raw material, and a resultant mixture is sufficiently mixed using a ball mill or the like. This mixture is fired at a firing temperature of, for example, about 1300°C to 1500°C for about 1 to 6 hours in a reductive atmosphere, e.g., in a stream of nitrogen-hydrogen mixture gas, and then cooled to room temperature for 1 to 6 hours. The material obtained

from the firing is ground and sieved to obtain a phosphorescent phosphor having a predetermined particle diameter.

Furthermore, at this time, the amount of europium (Eu) doped as an activator is expressed in terms of mol% relative to the total mole number of strontium (Sr), europium (Eu) as an activator and dysprosium (Dy) as a co-activator. For example, when 3 mol% of europium and 1.5 mol% of dysprosium are doped to strontium, compounds of the elements are blended so that the amount of strontium element is 0.955 mol, that the amount of europium element 0.03 mol and that the amount of dysprosium element is 0.015 mol. Consequently, relative to the total mole number of the elements (i.e., 1), the amount of europium is 3% in terms of mol%.

Moreover, in the aforementioned embodiment, the firing process is performed using a boron compound as flux. However, as long as the firing temperature is sufficiently high, e.g., about 1450°C, compared to a temperature required for the reaction, the firing process may be performed without flux. In this case, sinter of the material obtained from firing is so weak that its grinding becomes easy, thus making it possible to alleviate a luminance decrease by grinding.

An example of the above-mentioned embodiment will now be described.

First, a relation between the doped amounts of europium (Eu) and dysprosium (Dy) and initial afterglow luminance characteristics will be described.

First, 3.52 g (0.02 mol as Eu) of europium oxide ( $\text{Eu}_2\text{O}_3$ ) as a raw material of europium as an activator is doped to 143.20 g (0.97 mol) of strontium carbonate ( $\text{SrCO}_3$ ) as a raw material of strontium (Sr), 1.86 g (0.01 mol as Dy) of dysprosium oxide ( $\text{Dy}_2\text{O}_3$ ) as a raw material of dysprosium (Dy) as a co-activator is doped, 117.26 g (2.3 mol as Al, i.e.,  $\text{Al}/(\text{Sr}+\text{Eu}+\text{Dy})=2.3$ ) of alumina ( $\text{Al}_2\text{O}_3$ ) as an aluminum raw material is added thereto, 3.2 g (i.e., 1.2% by mass relative to the raw material) of boric acid ( $\text{H}_3\text{BO}_3$ ) is added thereto as a boron (B) compound as flux, and a resultant mixture is sufficiently mixed using a ball mill. This mixture is fired at a firing temperature of 1350°C for 4 hours in a stream of mixture gas of 97% of nitrogen and 3% of hydrogen as a reductive atmosphere, and then cooled to room temperature for about an hour. The fired material obtained was ground and sieved, and a resultant powder passing through a #250 mesh was determined to be phosphorescent phosphor Sample 1-(3). In this Sample 1-(3), the amount of europium relative to the total amount of strontium, europium and dysprosium is 2 mol%, the amount of dysprosium is similarly 1 mol%, and the molar ratio of dysprosium to europium, i.e.,  $\text{Dy}/\text{Eu}$ , is 0.5. Moreover, the molar ratio of aluminum, i.e.,  $\text{Al}/(\text{Sr}+\text{Eu}+\text{Dy})$ , is 2.3, which exceeds a stoichiometry ratio of 2.0.

Likewise, the molar ratio of dysprosium relative to europium, i.e.,  $\text{Dy}/\text{Eu}$ , was fixed to 0.5, and the amount of doped europium relative to the total mole number of strontium (Sr), europium (Eu) and dysprosium (Dy) was varied within the

range from 0.01 to 0.07 as shown in Table 1 to obtain phosphorescent phosphors as Sample 1-(1), Sample 1-(2), and Samples 1-(4) to 1-(6), respectively. Further, for a Comparative Example, as a conventional aluminate phosphorescent phosphor, the phosphorescent phosphor "N-Yako/LumiNova®" G-300M (Lot No. DM-092, NEMOTO & CO., LTD) that is one of the embodiments of the patent document 1 was employed as Comparative Example 1.

[Table 1]

Conditions	(Sr + Eu + Dy) = 1 mol Al/(Sr + Eu + Dy) = 2.3 (Comparative Example 1 = 2.0)		
Samples	Eu/(Sr+Eu+Dy) (molar ratio)	Dy/(Sr+Eu+Dy) (molar ratio)	Dy/Eu
Sample 1-(1)	0.01	0.005	0.5
Sample 1-(2)	0.015	0.0075	0.5
Sample 1-(3)	0.02	0.01	0.5
Sample 1-(4)	0.03	0.015	0.5
Sample 1-(5)	0.05	0.025	0.5
Sample 1-(6)	0.07	0.035	0.5

Next, the afterglow luminance characteristics of these Samples 1-(1) to 1-(6) and Comparative Example 1 were examined. Each sample powder was filled in a sample container made of aluminum, heated in advance at 120°C for about 2 hours in a dark place to remove afterglow, and then excited by a fluorescent lamp with a color temperature of 4200 K for 60 minutes at a brightness of 54 lx, i.e., under the excitation condition of low illumination, and thereafter the afterglow was measured using a luminance meter (chromaticity luminance meter BM-5A, TOPCON CORPORATION). The results thereof are

shown in Table 2 as relative luminance where the afterglow luminance of Comparative Example 1 is assumed to be 1.

[Table 2]

Excitation conditions	FL (4200K), 54 lx, 60 minutes				
Samples	Afterglow luminance characteristics (relative values where the value of Comparative Example 1 is 1.0)				
	5 minutes	10 minutes	20 minutes	60 minutes	90 minutes
Comparative Example 1	1.00	1.00	1.00	1.00	1.00
Sample 1-(1)	1.30	1.16	1.09	0.87	0.76
Sample 1-(2)	1.44	1.29	1.21	1.02	0.95
Sample 1-(3)	1.45	1.33	1.27	1.07	1.00
Sample 1-(4)	1.54	1.42	1.36	1.20	1.12
Sample 1-(5)	1.45	1.33	1.27	1.07	1.00
Sample 1-(6)	1.30	1.05	0.87	0.66	0.49

From the results shown in Table 2, it is apparent that in all of Samples 1-(3) to 1-(5), i.e., in the condition in which the amount of doped europium is 2 to 5 mol%, the afterglow luminance characteristics, particularly the initial afterglow luminance characteristics at 5 minutes after cessation of the excitation, are excellent showing not less than 1.4 times as high as that of Comparative Example 1, and the afterglow luminance characteristics at 90 minutes are not less than that of Comparative Example 1. Further, in Sample 1-(4), i.e., in the condition in which the amount of doped europium is 3 mol%, the afterglow luminance characteristics at 5 minutes is not less than 1.5 times as high as that of Comparative Example 1, and the afterglow luminance characteristics at 10 minutes is not less than 1.4 times as high as that of Comparative Example 1, and thus it is apparent that Sample 1-(4) is more preferable.

However, in Sample 1-(6), i.e., in the condition in which the amount of doped europium is 7 mol%, i.e., greater than 5%, the luminance decreases generally due to concentration quenching.

Moreover, in Sample 1-(2), i.e., in the condition in which the amount of doped europium is 1.5 mol%, though the afterglow luminance characteristics at 5 minutes after cessation of the excitation is preferable showing 1.44 times as high as that of Comparative Example 1, the afterglow luminance characteristics at 90 minutes is 0.95 times as high as Comparative Example 1, slightly lower than that of Comparative Example 1.

Further, in Sample 1-(1), i.e., in the condition in which the amount of doped europium is 1 mol%, the luminance decreases generally, and particularly the afterglow luminance characteristics at 90 minutes is 0.76 times as high as Comparative Example 1.

From these results, it is apparent that when the ratio of dysprosium to europium is fixed to 0.5 in the case of excitation under the excitation condition of low illumination, afterglow luminance characteristics superior to those of the conventional examples are obtained if the amount of doped europium ranges from more than 1.5 mol% to not more than 5 mol%.

The change of initial afterglow luminance characteristics as the ratio of the amounts of doped dysprosium and europium (Dy/Eu) is varied will now be described.

Principally in the condition for Sample 1-(4) which is considered preferable from the results shown in Table 2, i.e., in the condition in which the amount of doped europium relative to the total amount of strontium, europium and dysprosium is 3 mol%, and the ratio of dysprosium to europium (Dy/Eu) is 0.5, phosphorescent phosphors were prepared as Samples 1-(7) to 1-(14) under the same conditions as those for Sample 1-(3) except that the amount of doped europium was fixed to 3 mol% and that the value of Dy/Eu was varied within the range of 0.1 to 2.5 as shown in Table 3.

[Table 3]

	(Sr + Eu + Dy) = 1 mol Al/(Sr + Eu + Dy) = 2.3		
Samples	Eu/(Sr+Eu+Dy) (molar ratio)	Dy/(Sr+Eu+Dy) (molar ratio)	Dy/Eu
Sample 1-(7)	0.03	0.003	0.1
Sample 1-(8)	0.03	0.006	0.2
Sample 1-(9)	0.03	0.009	0.3
Sample 1-(10)	0.03	0.012	0.4
Sample 1-(4)	0.03	0.015	0.5
Sample 1-(11)	0.03	0.03	1
Sample 1-(12)	0.03	0.045	1.5
Sample 1-(13)	0.03	0.06	2
Sample 1-(14)	0.03	0.075	2.5

These Samples 1-(7) to 1-(14) were excited under the excitation condition of low illumination (4200 K fluorescent lamp, 54 lx, 60 minutes) in the same manner as described for Sample 1-(1), and their afterglow luminance characteristics were examined. The results thereof, as well as the results for Comparative Example 1 and Sample 1-(4), are shown in Table



4 as relative luminance where the afterglow luminance of Comparative Example 1 assumed to be 1.

[Table 4]

Excitation conditions	FL (4200K), 54 lx, 60 minutes				
Samples	Afterglow luminance characteristics (relative values where the value of Comparative Example 1 is 1.0)				
	5 minutes	10 minutes	20 minutes	60 minutes	90 minutes
Comparative Example 1	1.00	1.00	1.00	1.00	1.00
Sample 1-(7)	1.14	0.92	0.78	0.51	0.41
Sample 1-(8)	1.27	1.01	0.91	0.66	0.52
Sample 1-(9)	1.34	1.19	1.12	0.91	0.80
Sample 1-(10)	1.44	1.30	1.27	1.10	1.03
Sample 1-(4)	1.54	1.42	1.36	1.20	1.12
Sample 1-(11)	1.50	1.38	1.34	1.13	1.12
Sample 1-(12)	1.50	1.36	1.32	1.14	1.11
Sample 1-(13)	1.50	1.38	1.34	1.13	1.12
Sample 1-(14)	1.27	1.15	1.12	0.93	0.89

From these results shown in Table 4, it is apparent that in all of Samples 1-(10) to 1-(13), i.e., where the ratio of dysprosium to europium ranges from 0.4 to 2, the afterglow luminance characteristics, particularly the initial afterglow luminance characteristics at 5 minutes after cessation of the excitation are excellent showing not less than 1.4 times as high as that of Comparative Example. Further, in all of Samples 1-(4) and 1-(11) to 1-(13), i.e., where the ratio of dysprosium to europium ranges from 0.5 to 2, the afterglow luminance characteristics at 5 minutes are not less than 1.5 times as high as that of Comparative Example 1, and thus it is apparent these Samples have more preferable excellent afterglow luminance characteristics. However, it is apparent that in Samples 1-(7) to 1-(9), i.e., where the

ratio of dysprosium to europium ranges from 0.1 to 0.3, the amount of doped dysprosium contributing to afterglow luminance characteristics is so small compared to the amount of europium that the afterglow luminance characteristics deteriorate. Moreover, in Sample 1-(14), i.e., where the ratio of dysprosium to europium is 2.5, the amount of doped europium contributing to the fluorescent luminance and the initial afterglow luminance is small compared to the amount of dysprosium contributing to afterglow luminance characteristics, and therefore the initial afterglow luminance characteristics deteriorate.

From these results, it is apparent that when the amount of doped europium is fixed to 3 mol% in the case of excitation under the excitation condition of low illumination, afterglow luminance characteristics superior to those of the conventional examples are obtained if the ratio of dysprosium to europium (Dy/Eu) ranges from 0.4 to 2.0. Moreover, it was confirmed that a similar effect could be produced even if the amount of doped europium ranges from 1.5% to 5%.

Further, phosphorescent phosphor of Sample 1-(4) considered preferable in the above measurements, i.e., where the amount of doped europium was 3% and the amount of doped dysprosium was 1.5% was not excited under the excitation condition of low illumination as Comparative Example 1, but excited at a brightness of 400 lx with a D65 standard light source for 20 minutes as an example under normal light conditions, and afterglow luminance characteristics were

measured similarly. The results thereof are shown in Table 5 as relative luminance where the afterglow luminance of Comparative Example 1 assumed to be 1.

[Table 5]

Excitation conditions	D <sub>65</sub> standard light source, 400 lx, 20 minutes				
Samples	Afterglow luminance characteristics (relative values where the value of Comparative Example 1 is 1.0)				
	5 minutes	10 minutes	20 minutes	60 minutes	90 minutes
Comparative Example 1	1.00	1.00	1.00	1.00	1.00
Sample 1-(4)	1.20	1.19	1.12	1.04	1.01

As apparent from these results shown in Table 5, improvement in afterglow luminance characteristics was recognized compared to Comparative Example 1 when the phosphorescent phosphor of Sample 1-(4) was excited at a brightness of 400 lx with the D65 standard light source for 20 minutes. However, since the effect is only about 1.2 times as high as that of Comparative Example 1 in the afterglow luminance at 5 minutes after cessation of the excitation, for example, that is limited to a slight effect compared to a remarkable effect that the afterglow luminance at 5 minutes after cessation of the excitation is 1.54 times as high as that of Comparative Example 1 for the same samples excited under the excitation condition of low illumination (4200 K fluorescent lamp/54 lx/60 minutes) (cf. Table 2). From this fact, it is apparent that phosphorescent phosphor of Sample 1-(4), at least, has more excellent afterglow luminance characteristics under the excitation condition of low

illumination (e.g., 4200 K fluorescent lamp, 54 lx, 60 minutes) than under excitation conditions by normal light (e.g., D65 standard light source, 400 lx, 20 minutes). Likewise, under normal light excitation conditions, phosphorescent phosphors of Samples 1-(2), 1-(3) and 1-(10) to 1-(13) were checked, and resultantly found to have tendencies similar to that of Sample 1-(4).

From the results of measurements of the afterglow luminance of Samples 1-(1) to 1-(14) described above, it is apparent that by doping europium (Eu) in the amount more than 1.5% and not more than 5% in terms of mol% relative to the total mole number of strontium (Sr), europium (Eu) and dysprosium (Dy), and by doping dysprosium (Dy) in the ratio of  $0.4 \leq \text{Dy}/\text{Eu} \leq 2$  in terms of a molar ratio relative to europium (Eu), the afterglow luminance characteristics, particularly the initial afterglow luminance characteristics, become superior to those of conventional phosphorescent phosphors particularly in the case of excitation under the excitation condition of low illumination, and thus a phosphorescent phosphor having unprecedented new characteristics is obtained.

In the case where a compound expressed as  $\text{SrAl}_2\text{O}_4$  as a matrix, the molar ratio of aluminum (Al) relative to the total mole number of strontium (Sr), europium (Eu) and dysprosium (Dy) and the afterglow luminance characteristics will now be described.

To 140.99 g (0.955 mol) of strontium carbonate ( $\text{SrCO}_3$ ) as a raw material of strontium (Sr) is doped 5.28 g (0.03 mol as Eu) of europium oxide ( $\text{Eu}_2\text{O}_3$ ) as a raw material of europium as an activator, 2.80 g (0.015 mol as Dy) of dysprosium oxide ( $\text{Dy}_2\text{O}_3$ ) as a raw material of dysprosium (Dy) as a co-activator is doped, 104.51 g (2.05 mol as Al, i.e.,  $\text{Al}/(\text{Sr}+\text{Eu}+\text{Dy})=2.05$ ) of alumina ( $\text{Al}_2\text{O}_3$ ) as an aluminum raw material is added, 3.0 g (i.e., 1.2% by mass relative to the raw material) of boric acid ( $\text{H}_3\text{BO}_3$ ) as a boron (B) compound as flux is added, and a resultant mixture is sufficiently mixed using a ball mill. This mixture is fired at a firing temperature of  $1350^\circ\text{C}$  for 4 hours in a stream of mixture gas of 97% of nitrogen and 3% of hydrogen as a reductive atmosphere, and then cooled to room temperature for about an hour. The fired material obtained was ground and sieved, and a resultant powder passing through a #250 mesh was determined to be phosphorescent phosphor Sample 2-(3). In this Sample 2-(3), the amount of doped europium relative to the total amount of strontium, europium and dysprosium is 3 mol%, the amount of doped dysprosium is similarly 1.5 mol%, and the molar ratio of dysprosium to europium, i.e.,  $\text{Dy}/\text{Eu}$ , is 0.5. Moreover, the molar ratio of aluminum, i.e.,  $\text{Al}/(\text{Sr}+\text{Eu}+\text{Dy})$ , is 2.05, which exceeds a stoichiometry ratio of 2.0.

Likewise, the molar ratio of aluminum, i.e.,  $\text{Al}/(\text{Sr}+\text{Eu}+\text{Dy})$  was varied within the range from 2.0 to 2.6 as shown in Table 6 to obtain phosphorescent phosphors as Samples 2-(1), 2-(2) and 2-(4) to 2-(8). Furthermore, for Sample 2-(6),

i.e., the sample with the molar ratio of aluminum of 2.4, powder X-ray diffraction analysis was carried out using a Cu vessel, and a diffraction chart was obtained. This is shown in Fig. 1.

[Table 6]

Conditions	Eu=3 mol%, Dy=1.5 mol% (relative to Sr+Eu+Dy)
Samples	Al/(Sr + Eu + Dy)
Sample 2-(1)	2.0
Sample 2-(2)	2.02
Sample 2-(3)	2.05
Sample 2-(4)	2.1
Sample 2-(5)	2.2
Sample 1-(4)	2.3
Sample 2-(6)	2.4
Sample 2-(7)	2.5
Sample 2-(8)	2.6

Next, these Samples 2-(1) to 2-(8) were excited under the excitation condition of low illumination (4200 K fluorescent lamp, 54 lx, 60 minutes) in the same manner as described for Sample 1-(1), and their afterglow luminance characteristics were examined. The results thereof, as well as the results for Sample 1-(4) excited under the same conditions except for the molar ratio of aluminum is 2.3, are shown in Table 7 as relative luminance where the afterglow luminance of Comparative Example 1 assumed to be 1.

[Table 7]

Excitation conditions	FL (4200K), 54 lx, 60 minutes				
Samples	Afterglow luminance characteristics (relative values where the value of Comparative Example 1 is 1.0)				
	5 minutes	10 minutes	20 minutes	60 minutes	90 minutes
Comparative Example 1	1.00	1.00	1.00	1.00	1.00
Sample 2-(1)	1.48	1.32	1.21	1.02	0.92
Sample 2-(2)	1.60	1.46	1.34	1.15	1.07
Sample 2-(3)	1.69	1.55	1.46	1.27	1.18
Sample 2-(4)	1.68	1.51	1.42	1.25	1.16
Sample 2-(5)	1.60	1.46	1.38	1.22	1.14
Sample 1-(4)	1.54	1.42	1.36	1.20	1.12
Sample 2-(6)	1.43	1.33	1.30	1.14	1.08
Sample 2-(7)	1.37	1.29	1.21	1.06	1.01
Sample 2-(8)	1.28	1.21	1.14	1.00	0.94

From the results shown in Table 7, it is apparent that in all of Samples 2-(2) to 2-(6), i.e., where the molar ratio of aluminum ranges from 2.02 to 2.4, the afterglow luminance characteristics, particularly the initial afterglow luminance characteristics at 5 minutes after cessation of the excitation are excellent showing not less than 1.4 times as high as that of Comparative Example 1, and the afterglow luminance characteristics at 90 minutes are excellent showing more than that of Comparative Example 1. Further, in Samples 2-(2) to 2-(5) (the molar ratio of aluminum ranges from 2.02 to 2.2), especially the initial afterglow luminance at 5 minutes are not less than 1.6 times or more times as high as that of Comparative Example 1, and thus it is apparent that these samples have more preferable excellent afterglow luminance characteristics. Their excellent afterglow luminance characteristics are ascribable to the fact that the molar ratio of aluminum is greater than 2.0 and not less than

2.02, so that crystals are preferably distorted. However, in Sample 2-(1) (the molar ratio of aluminum is 2.0), the afterglow luminance characteristics at 90 minutes, for example, is less than that of Comparative Example 1; in Sample 2-(7) (the molar ratio of aluminum is 2.5), the afterglow luminance after 5 minutes slightly lowers to 1.37 times; and in Sample 2-(8) (the molar ratio of aluminum is 2.6), a general decrease in afterglow luminance is observed. The general decrease in luminance is ascribable to the fact that the molar ratio of aluminum increases, whereby occurrence of, for example, aluminates other than  $\text{SrAl}_2\text{O}_4$ , as by-products increases.

From this fact, it is apparent that when a compound expressed by  $\text{SrAl}_2\text{O}_4$  is used as a matrix, a phosphorescent phosphor having excellent afterglow luminance characteristics is obtained in case that the molar ratio of aluminum relative to the total mole number of strontium, europium and dysprosium, i.e.,  $\text{Al}/(\text{Sr}+\text{Eu}+\text{Dy})$  ranges from 2.02 to 2.4.

#### Industrial Applicability

The present invention can be applicable for safety applications for use in low illumination environments, such as release handles for escape in automobile trunks and safety signs for escape guidance in subway systems, tunnels, ships, airplanes and the like.